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The influence of the monsoon climate on phytoplankton in the Shibpukur pool of Shiva temple in Burdwan, West Bengal, India

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Abstract: A total of 44 taxa were observed in monthly sampled phytoplankton of the Shibpukur pool in Burdwan, West Bengal between March, 2010 and February, 2011. The most abundant taxa belong to Charophyta, followed by cyanobacteria, diatoms and euglenoids. Bio-indication shows that the pool community preferred low alkaline, low mineralized and low organically polluted water. The total phytoplankton density showed its maximum values in May, 2010. The Shannon-Weaver diversity index and the Pielou evenness value were found to be highest during the post-monsoon season. The Simpson dominance index and the Margalef index of richness were highest in the pre-monsoon season. The total phytoplankton density showed a highly significant positive correlation with pH and salinity and significant positive correlation with air temperature, water temperature, dissolved oxygen and total suspended solids. Among the reported 44 phytoplankton taxa only 3 showed a random distributional pattern. The Bray-Curtis Cluster analysis and the comparative statistics reveal two groups of phytoplankton assemblages in respect to the monsoon seasons. The successive communities form a continuum corresponding to Colwell's Constancy (C) category. The calculated indices, CCA, and bio-indication analysis exhibit a low pollution level in the Shibpukur pool that can be used as a model of aquatic community dynamics under seasonal fluctuation in the monsoon climate, applicable for monitoring of water bodies in the West Bengal Province.

Key words: Phytoplankton, monsoon climate, natural reserve, West Bengal, India

Introduction

Temporal changes in the composition of phytoplankton are of utmost importance to the aquatic system's health. The planktonic algae are primary producers and are at the base of the trophic cascade with zooplankton, shell fish, fin fish and with other higher aquatic animals. So a minute change in the composition of the phytoplankton community can modify the food-web structure and the energy flow through the aquatic ecosystem. The phytoplankton contains diverse prokaryotic and eukaryotic organisms. According to Wetzel (1975) well-developed phytoplankton communities are normally restricted to stagnant water bodies and large slow rivers, whereas higher flow rates can disturb and disintegrate the phytoplankton structure. Various interacting environmental factors regulate the temporal changes in the composition of phytoplankton, its stability and predictability of changes (Colwell 1974). Temperature and light are climatic dependent variables, and are the key drivers which help to establish phytoplankton in the euphotic zone, as well as controlling availability of micro and macro nutrients and succession strategies (Reynolds 1984; Harris 1987). Species of phytoplankton can be used as indicators of water quality (Palmer et al. 1977; Shubert 1984). They also play a decisive role in the global biogeochemical cycling (Broecker 1974).

Though species composition and the seasonal dynamics of phytoplankton of stagnant water bodies of India have been investigated by several authors during the last century (Biswas 1949; Abraham 1962; Jana et al. 1980; Unni 1982; Verma et al. 1984; Zutshi 1989; Gopal and Zutshi 1998; Ghosh and Keshri 2010, 2011; Senapati et al. 2011), the relationships between algal communities' structure and environment is insufficiently studied (Ghosh et al. 2012) in respect to the monsoon climatic conditions.

The purpose of this study was to elucidate the changes in the composition of phytoplankton as a temporal variable of the influence of the monsoon climate. Phytoplankton composition, its seasonal changes and the diversity characteristics of the Shibpukur pool have not been previously explored. The studied water body, typical for this area, is almost undisturbed by any anthropogenic sources and is partly covered by trees and herbaceous vegetation. The area is located adjacent to the Ramnabagan Wildlife Sanctuary, Burdwan province, West Bengal. The environmental factors which are the principal contributors to the temporal fluctuation of phytoplankton communities are characterized by ecological indicators obtained in the course of the community structure analysis, involving various diversity indices and statistical approaches.

Description of the study site

In the West Bengal Province, the River Ganga valley abounds in small pools that occur in urbanized areas. The studied pool is located at 23°15'14.5" N, 87°51'10.5" E and 20 metres above sea level. This pool is rectangular in shape 50 m long and 25 m wide, shallow (to one m deep) and has a very small catchment basin area because all the surroundings are urbanized, except a 50 m zone around the pool itself (Fig. 1). The water body under consideration is located in the Burdwan district of West Bengal. It is locally known as "Shibpukur" of Shiva Temple Natural Reserve. Now only this water body and the temple are maintained by Burdwan Maharaja Trusty. The whole area is within a natural forest patch developed during the periods of the Rajas and Maharajas of Burdwan Taluk (Sarkar 2008) and after the implementation of the Estate Acquisition Act, it was handed over to the West Bengal Forest Department for proper management and maintenance.

Experimental procedures

To study the temporal changes in the phytoplankton composition of a water body in the Burdwan district of West Bengal, India, monthly samplings from March 2010 to February 2011 were undertaken. Here for the construction of a seasonal framework we have designated the months March, April, May as summer; June, July, August as pre-monsoon; September, October, November as monsoon and December, January, February as post-monsoon season. The geographic coordinates of the water body under study were determined by the GARMIN GPS map 76 CSx device. The location map was constructed with the help of ArcGis 10.0 software.

In parallel with phytoplankton sampling, measurements were taken of air and water temperature by thermometer, electrical conductivity, total dissolved solids, salinity, dissolved oxygen and pH of water by Oakton waterproof Multiparameter Tester PCS 35 and Oakton portable DO Meter.

Phytoplankton samples were collected in 400 ml amber coloured bottles between 9 to 10 am and preserved with acetic Lugol's solution (Sournia 1978). The collected samples were left for two days for sedimentation. Then the supernatant was withdrawn using a pipette, leaving the settled cells in the bottom. The drop count method (Trivedy and Goel 1984) was practised for quantitative estimation of phytoplankton. Phytoplankton was studied with an Olympus GB microscope under magnifications of 960-1500 and for taxonomic identification prism drawings were done. Phytoplankton densities were calculated as cells per litre. The algal abundances were scored for indices calculation (Table 1). For identification we used handbooks (Cox 1996; Desikachary 1959; Hustedt 1930; Krammer and Lange-Bertalot 1991, 1997a,b,c; Komárek and Anagnostidis 1998, 2005; Prescott 1962; Smith 1950; Turner 1982; Wehr and Sheath 2003). The list of revealed species was arranged alphabetically according to M.D. Guiry and G.M. Guiry (2011) updated taxonomic system.

Table 1. Phytoplankton species abundance score scale (Barinova et al. 2006)

Score	Visual estimate	Cell numbers per slide
1	Occasional	1-5
2	Rare	10-15
3	Common	25-30
4	Frequent	1 cell over a slide transect
5	Very frequent	Several cells over a slide transect
6	Abundant	One or more cells in each field of view

The ecological and geographical characteristics of algal species were obtained from the database compiled for freshwater algae from multiple analyses of algal biodiversity (Barinova et al. 2006) with additions (Ter Braak and Van Dam 1989; Van Dam et al. 1994) according to substrate preference, temperature, streaming and oxygenation, pH, salinity, organic enrichments, N-uptake metabolism, and trophic states.

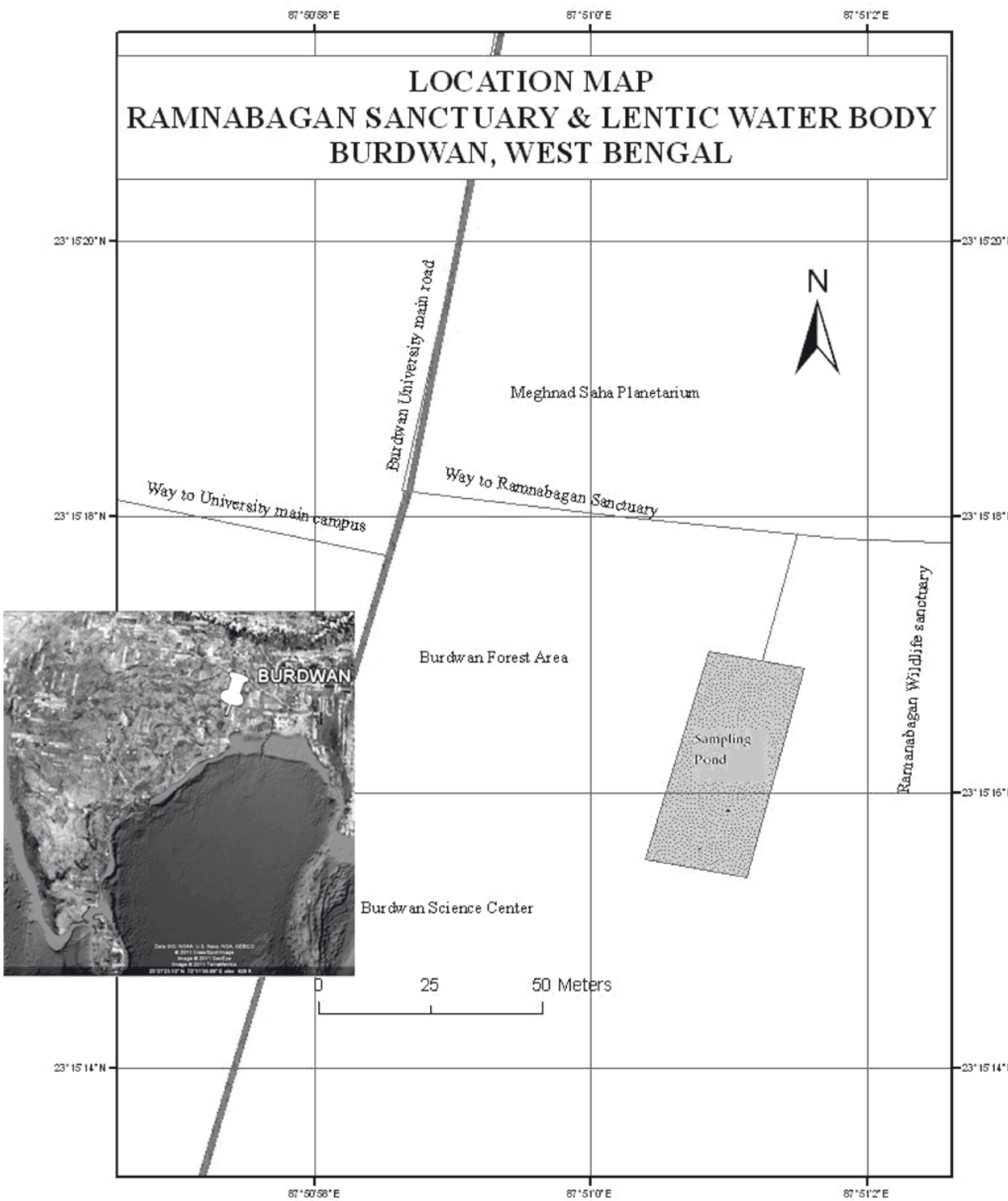

Fig. 1. Map of the study site of the Shibpukur pool in the Burdwan district, West Bengal

The ecological groups were separately assessed according to their significance for bio-indications. Species that respond predictably to environmental conditions were used as bio-indicators for particular variables of aquatic ecosystems, the dynamics of which is related to environmental changes. Indices of saprobity and water quality classes were calculated after Sládeček (1973).

The specific diversity calculation was deciphered from Shannon and Weaver (Shannon and Weaver 1949) as follows:

$$H' = -\sum p_i \ln p_i ,$$

where: H' is the species diversity value, and p_i is the proportion of individuals found in its species.

Specific dominance was calculated from Simpson's equation (Simpson 1949):

$$D = \sum \left(\frac{n_i [n_i - 1]}{N[N - 1]} \right),$$

where: D is the specific dominance value, n_i is the number of individuals in its species, and N is the total number of individuals.

The evenness index was calculated by the Shannon evenness measurement process (Pielou 1969, 1975) in the following way:

$$J' = H'/H_{\max} = H'/\ln S ,$$

where: J' is the evenness index, and H_{max} is the maximum diversity that could possibly be found in a condition where all species had equal abundance values i.e. $H' = H_{\max} = \ln S$

Species richness index was calculated following Margalef's diversity index (Clifford and Stephenson 1975):

$$D_{MG} = (S - 1)/\ln N ,$$

where: D_{MG} is Margalef's diversity index, S is the number of species found, and N is the total number of individuals within the sample.

All diversity indices were calculated as log base 2 values from the software BioDiversity Pro, Ver. 2 (McAleece et al. 1997). Physico-chemical parameters such as water temperature, air temperature, pH, conductivity, salinity, total dissolved solid, and dissolved oxygen were analysed by Oakton waterproof Multiparameter Tester PCS 35 and Oakton portable DO Meter.

Structural diversity was calculated using statistical methods recommended by Heywood (2004) for floristic and taxonomic studies. We established the correlation of species composition and environmental variables using Canonical Correspondence Analysis (CCA) with CANOCO Program for Windows 4.5 package (Ter Braak and Šmilauer 2002). Statistical significance of each variable was assessed using the Monte Carlo unrestricted permutation test involving 999 permutations (Ter Braak 1990). The abbreviated names of species are given in the taxonomic table. The CCA plots represent overlap of species in relation to a given combination of environmental variables in the studied month. Arrows represent environmental variables, with the maximal influence value for each variable located at the tip of the arrow (Ter Braak 1987). The Multiple Regression Analysis indicated a range of fluctuations in the algal community relative to the environmental variables by construction of a correlation matrix between phytoplankton density and environmental variables and stepwise regression analysis with IBM SPSS 19.0, Bray Curtis cluster analysis with BioDiversity pro Ver. 2.0 program (McAleece et al. 1997) and comparative floristic studies with GRAPHS program (Novakovsky 2004).

Results

A total number of 44 species of phytoplankton of five taxonomic divisions, Charophyta (13), Cyanobacteria (12), Bacillariophyta (8), Chlorophyta (7), and Euglenozoa (4) were identified from the pool from March 2010 to February 2011 (Table 2). The monsoon season is represented by the maximum number of phytoplankton taxa (42), and the pre-monsoon season with the lowest number (34). Among the 44 phytoplankton taxa, charophytes were dominant throughout the study period. The percentage composition of the studied phytoplankton (Fig. 2) reflects the uniform pattern of their representation (Charophyta > Cyanobacteria > Bacillariophyta > Chlorophyta > Euglenozoa) during the whole study period. The phytoplankton density was highest in summer followed by the post-monsoon, monsoon and pre-monsoon densities (Table 3). The Shannon-Weaver diversity index (H') value (3.618) and the Pielou evenness (J') value (0.984) were found to be highest during the

Table 2. Diversity and ecology of algal species in plankton of the Shibpukur pool of the Burdwan district in March 2010 – February 2011

No	Taxa	Sub	T	Oxy	D	Sal	pH	S	Sap	Aut	Tro
	Cyanobacteria										
1	*Dolichospermum circinale (Rabenhorst ex Bornet & Flahault) P.Wacklin, L.Hoffmann & J.Komárek*	P	–	–	–	i	–	2.1	b	–	–
2	*Aphanocapsa grevillei (Hassall) Rabenhorst*	B,S	temp	–	–	hb	acf	1.4	o-b	–	–
3	*Aphanocapsa litoralis (Hansgirg) Komárek & Anagnostidis*	P-B	–	–	–	–	–	–	–	–	–
4	*Aphanocapsa pulchra (Kützing) Rabenhorst*	–	–	–	–	–	–	–	–	–	–
5	*Chroococcus turgidus (Kützing) Nägeli*	P-B,S	–	–	–	hl	alf	1.3	o	–	–
6	*Cylindrospermum bengalense Biswas*	–	–	–	–	–	–	–	–	–	–
7	*Merismopedia elegans A.Braun ex Kützing*	P-B	–	–	–	i	ind	1.7	b-o	–	–
8	*Merismopedia glauca (Ehrenberg) Kützing*	P-B	–	–	–	i	ind	1.8	o-a	–	–
9	*Merismopedia punctata Meyen*	P-B	–	–	–	i	ind	1.9	o-a	–	–
10	*Phormidium formosum (Bory de Saint-Vincent ex Gomont) Anagnostidis et Komárek*	P-B,S	–	st	–	–	–	2.8	b-p	–	–
11	*Spirulina major Kützing ex Gomont*	P,S	–	st	–	ph	–	3.0	a	–	–
12	*Spirulina subsalsa Örstedt ex Gomont*	B	–	st-str	–	–	–	1.4	o-b	–	–
	Bacillariophyta										
13	*Discostella glomerata (H.Bachmann) Houk et Klee*	–	–	–	–	–	–	–	–	–	–
14	*Eunotia sp.*	–	–	–	–	–	–	–	–	–	–
15	*Navicula trivialis Lange-Bertalot*	B	–	st-str	sp	i	alf	1.7	b-o	ate	e
16	*Nitzschia linearis (C.Agardh) W.Smith*	B	temp	st-str	es	i	alf	0.0	x	ate	me
17	*Nitzschia obtusa W.Smith*	B	–	–	es	mh	–	–	b	–	–
18	*Pinnularia major (Kützing) Rabenhorst*	B	temp	st-str	–	i	ind	0.3	x	ate	me
19	*Surirella capronii Brébisson ex F.Kitton*	P-B,S	–	st	–	i	ind	0.3	x	-	me
20	*Ulnaria capitata (Ehrenberg) P.Compère*	B	–	–	–	–	–	1.5	o-b	–	–
	Euglenozoa										
21	*Euglena viridis (O.F.Müller) Ehrenberg*	P-B,S	eterm	st-str	–	mh	ind	4.1	i	–	–
22	*Phacus acuminatus Stokes*	P-B	eterm	st-str	–	i	–	2.5	b-a	–	–
23	*Phacus longicauda (Ehrenberg) Dujardin*	P-B	–	st	–	i	ind	2.6	a-b	–	–
24	*Phacus pleuronectes (O.F.Müller) Nitzsch ex Dujardin*	P-B	–	st-str	–	i	ind	2.4	b-a	–	–
	Chlorophyta										
25	*Chlamydomonas globosa J.W.Snow*	P,S	–	–	–	–	–	1.9	o-a	–	–
26	*Chlorella vulgaris Beijerinck*	P-B, pb, S	–	–	–	hl	–	3.1	a	–	–
27	*Coelastrum sphaericum Nägeli*	P-B	–	st-str	–	i	–	1.0	o	–	–
28	*Crucigenia tetrapedia (Kirchner) Kuntze*	P-B	–	st-str	–	i	ind	1.9	o-a	–	–
29	*Desmodesmus armatus (R.Chodat) Hegewald*	P-B	–	st-str	–	–	–	1.9	o-a	–	–
30	*Monoraphidium contortum (Thuret) Komàrková-Legnerová*	P-B	–	st-str	–	–	–	2.2	b	–	–
31	*Pediastrum duplex Meyen*	P	–	st-str	–	i	ind	1.8	o-a	–	–
	Charophyta										
32	*Staurodesmus quiriferus (West & G.S.West) Teiling*	–	–	–	–	–	–	–	–	–	–
33	*Cosmarium angulatum (Perty) Rabenhorst*	–	–	–	–	–	–	–	–	–	–
34	*Cosmarium connatum Brébisson ex Ralfs*	–	–	–	–	–	–	–	–	–	–
35	*Cosmarium javanicum Nordstedt*	–	–	–	–	–	–	–	–	–	–
36	*Cosmarium quasillus P.Lundell*	–	–	–	–	–	–	–	–	–	–
37	*Cosmarium trilobulatum Reinsch*	–	–	–	–	–	–	–	–	–	–
38	*Desmidium baileyi (Ralfs) Nordstedt*	–	–	–	–	–	–	–	–	–	–
39	*Micrasterias foliacea Bailey ex Ralfs*	–	–	–	–	–	–	–	–	–	–
40	*Netrium oblongum (De Bary) Lütkemüller*	–	–	–	–	–	–	0.8	x-b	–	–
41	*Onychonema sp.*	–	–	–	–	–	–	–	–	–	–
42	*Pleurotaenium granuliferum (Joshua) Hirano*	–	–	–	–	–	–	–	–	–	–
43	*Spondylosium planum (Wolle) West et G.S.West*	P	–	–	–	i	–	1.8	o-a	–	–
44	*Staurastrum cingulum (West et G.S.West) G.M.Smith*	P	–	st-str	–	–	–	–	–	–	–

Note: Ecological types (Sub): B, benthic; P, planktic; P–B, planktic-benthic; pb, phycobiont; S, soil. Temperature (T): temp, temperate; eterm, eurythermic. Streaming and oxygenation (Oxy): st, standing water; st-str, standing-streaming. Saprobity (Watanabe et al. 1986) (D): es, eurysaprob; sp, saprophil. Halobity (Sal) (Hustedt 1938-1939): ph, polyhalobe; mh, mesohalobe; i, oligohalobious-indifferent; hl, oligohalobious-halophilous; hb, oligohalobious-halophobous. Acidity (pH) (Hustedt 1957): ind, indifferent; alf, alkaliphil; acf, acidophil. Species-specific index of organic pollution (Sládeček 1986) (S). Saprobity (Sládeček 1986) (Sap): o, oligosaprob; o-b, oligo-beta-mesosaprob; b, beta-mesosaprob; b-o, beta-oligomesosaprob; b-a, beta-alfa-mesosaprob; a, alfa-mesosaprob; a-b, alfa-beta-mesosaprob; x, xenosaprob; x-b, xeno-beta-mesosaprob; o-a, oligo-alfa-mesosaprob; b-p, beta-polysaprob; i, eusaprob. Nitrogen uptake metabolism (Aut) (Van Dam et al. 1994): ate, nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen. Trophic state (Tro) (Van Dam et al. 1994): me, meso-eutraphentic; e, eutraphentic.

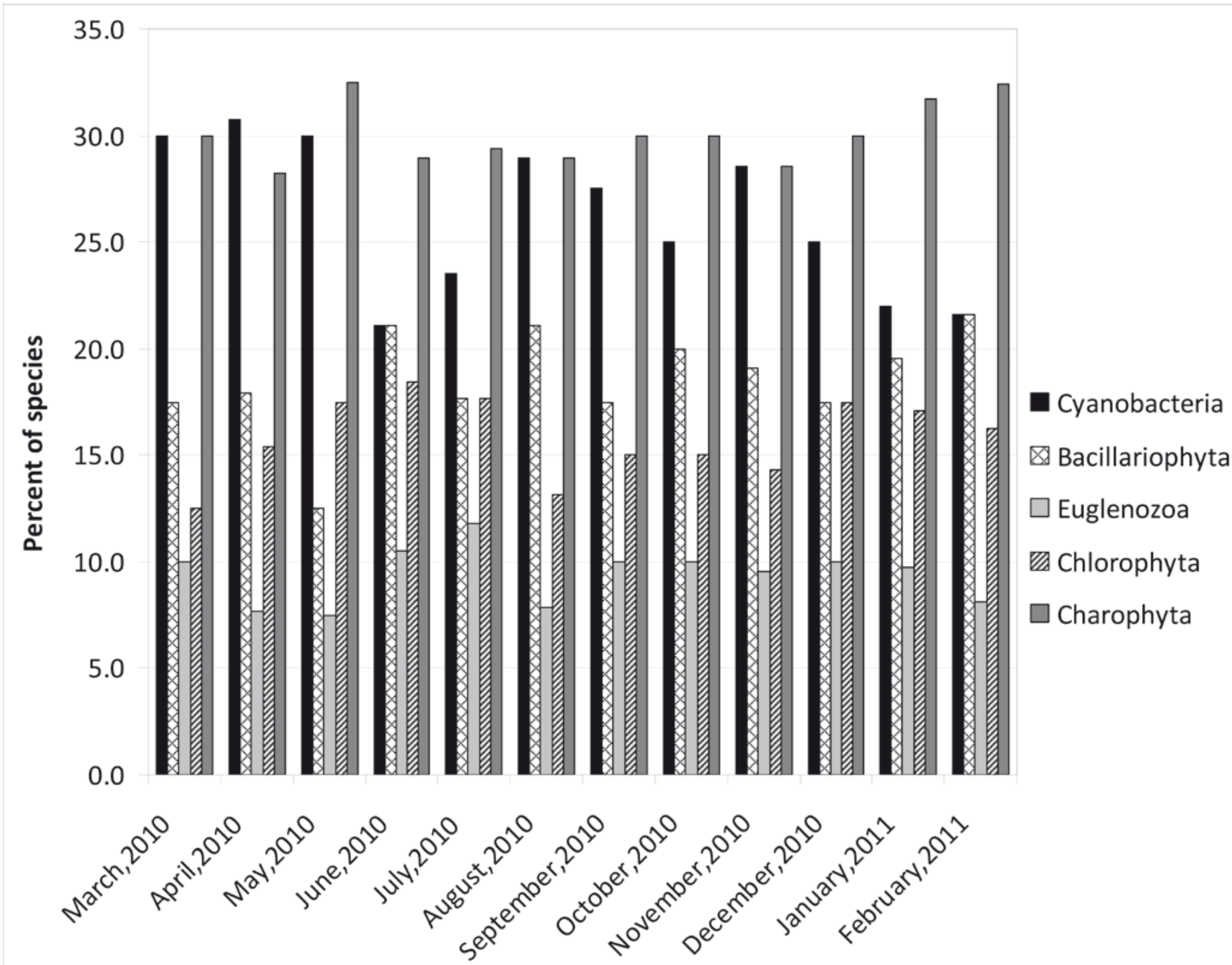

Fig. 2. Dynamics of phytoplankton community composition as a percentage of taxonomic divisions

post-monsoon season (Fig. 3). Simpson's dominance (D) index value (0.037) and Margalef's index of richness (D_{MG}) (7.822) showed their highest values in the pre-monsoon season.

The chemical variables slightly fluctuated during the studied period (Fig. 4) with the same amplitude of TDS, water and air temperature. The species numbers and abundance fluctuated in parallel, but opposite to TDS and temperature, and correlated with the Shannon indices values (Fig. 5).

An attempt was made to establish a correlation between chemical and biological variables (Table 4). Phytoplankton density showed a highly significant positive correlation with pH and salinity ($p < 0.01$), a significant positive correlation with air temperature, water temperature, dissolved oxygen and total suspended solids ($p < 0.05$), and a negative correlation with electrical conductivity (Table 5). In the regression analysis (Table 6) a mathematical model to ascertain the relationship between variables was proposed. The following model is used for the ordinary least square method regression:

PHYTOPLANKTON DENSITY = α + β1 AIR TEMPERATURE + β2 WATER TEMPERATURE + β3 pH + β4 SALINITY + β5 DISSOLVED OXYGEN + β6 ELECTRICAL CONDUCTIVITY + β7 TOTAL DISSOLVED SOLIDS + e

The response variable is phytoplankton diversity and the explanatory variables include air temperature, water temperature, pH, salinity, dissolved oxygen, electrical conductivity, and total dissolved solids, while e denotes the random disturbance term for the

Table 3. Diversity and abundance (cells per litre) of algal species in plankton of the Shibpukur pool of the Burdwan district in March 2010 – February 2011. The abbreviation names are given for each species in the column code. In the upper row as bold numbers are given the months of monitoring between March, 2010 as 1, and February, 2011 as 12

No	Taxa	Code	1	2	3	4	5	6	7	8	9	10	11	12
	Cyanobacteria													
1	*Dolichospermum circinale*	*AnCir*	11	11	22	2	2	5	6	0	11	0	0	0
2	*Aphanocapsa grevillei*	*AphaGr*	23	22	45	12	12	10	12	8	8	8	9	10
3	*Aphanocapsa litoralis*	*AphaLi*	21	22	44	11	10	12	17	11	11	20	22	22
4	*Aphanocapsa pulchra*	*AphaPu*	22	33	44	11	0	14	17	11	11	22	22	22
5	*Chroococcus turgidus*	*ChroTu*	22	33	55	11	12	12	14	22	22	22	22	20
6	*Cylindrospermum bengalense*	*CylBen*	3	5	11	2	2	0	1	1	3	6	6	0
7	*Merismopedia elegans*	*MerEle*	32	32	64	16	0	8	0	0	8	8	16	16
8	*Merismopedia glauca*	*MerGla*	16	16	32	0	16	16	8	8	8	8	0	0
9	*Merismopedia punctata*	*MerPun*	16	16	32	0	0	16	8	8	8	8	0	0
10	*Phormidium formosum*	*OscFor*	22	12	33	0	0	1	11	11	11	13	14	14
11	*Spirulina major*	*SpiMaj*	11	13	33	9	11	10	15	11	12	0	3	9
12	*Spirulina subsalsa*	*SpiSub*	22	22	43	0	2	11	13	13	14	15	11	11
	Bacillariophyta													
13	*Discostella glomerata*	*CycGlo*	2	2	2	5	0	3	5	5	6	6	7	15
14	*Eunotia sp.*	*Eunot*	12	10	12	3	3	1	6	7	8	9	9	15
15	*Navicula trivialis*	*NavLan*	11	10	0	2	2	1	8	8	9	11	15	15
16	*Nitzschia linearis*	*NitLin*	0	1	1	4	3	2	1	5	7	8	8	18
17	*Nitzschia obtusa*	*NitObt*	4	0	2	11	3	3	0	5	5	6	6	22
18	*Pinnularia major*	*PinMaj*	3	3	0	1	0	2	4	4	1	4	7	12
19	*Surirella capronii*	*SurCap*	3	3	0	1	1	1	4	4	5	4	5	11
20	*Synedra capitata*	*SynCap*	3	3	4	1	1	3	5	5	8	0	12	12
	Euglenozoa													
21	*Euglena viridis*	*EugVir*	2	2	6	7	9	0	3	3	2	5	5	6
22	*Phacus acuminatus*	*PhaAcu*	3	3	3	5	14	5	6	6	3	3	5	0
23	*Phacus longicauda*	*PhaLon*	3	3	0	1	8	16	5	5	5	7	11	11
24	*Phacus pleuronectes*	*PhaPle*	5	0	11	11	16	17	12	4	5	6	7	7
	Chlorophyta													
25	*Chlamydomonas globosa*	*ChlaGl*	0	12	11	10	3	4	12	14	15	11	16	0
26	*Chlorella vulgaris*	*ChloVu*	0	0	23	8	8	9	11	11	10	16	16	19
27	*Coelastrum sphaericum*	*CoelSp*	11	16	12	11	6	0	0	0	4	8	8	9
28	*Crucigenia tetrapedia*	*CruTet*	12	22	24	12	6	0	11	11	16	18	19	18
29	*Desmodesmus armatus*	*SceArm*	22	42	33	21	6	12	15	16	18	22	24	30
30	*Monoraphidium contortum*	*AnkFa*	11	16	15	4	0	3	4	4	0	7	8	9
31	*Pediastrum duplex*	*PedDup*	23	43	22	12	11	8	13	15	15	16	18	19
	Charophyta													
32	*Staurodesmus quiriferus*	*ArthQu*	12	21	11	11	7	10	13	13	15	16	18	18
33	*Cosmarium angulatum*	*CosAng*	5	0	13	2	5	6	11	12	12	14	16	22
34	*Cosmarium connatum*	*CosCon*	11	34	11	7	3	3	4	4	5	11	12	16
35	*Cosmarium javanicum*	*CosJav*	12	22	11	4	0	0	2	3	11	12	16	18
36	*Cosmarium quasillus*	*CosQua*	20	34	24	0	0	4	12	12	11	14	16	18
37	*Cosmarium trilobulatum*	*CosTri*	13	22	21	8	3	0	3	3	7	11	12	10
38	*Desmidium baileyi*	*DesBai*	15	16	5	0	0	11	11	11	10	8	9	9
39	*Micrasterias foliacea*	*MicFol*	22	21	22	11	11	8	9	9	9	11	12	12
40	*Netrium oblongum*	*NetObl*	22	28	22	11	11	13	0	0	15	14	16	0
41	*Onychonema sp.*	*Onycho*	13	33	33	12	11	11	8	12	13	13	14	16
42	*Pleurotaenium granuliferum*	*PleGra*	15	0	13	11	10	8	9	11	13	13	16	17
43	*Spondylosium planum*	*SpoPla*	15	23	21	11	11	7	11	12	0	0	12	17
44	*Staurastrum cingulum*	*StaCin*	0	22	11	8	5	12	14	15	16	16	21	20

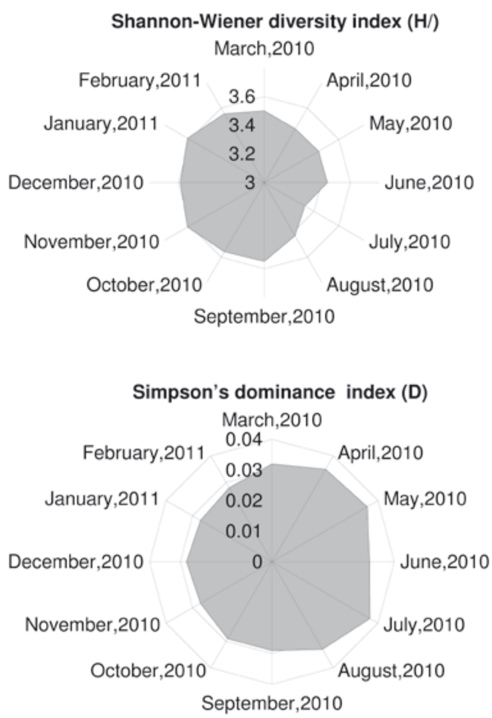

Fig. 3. Variation of Biological Indices during the studied period

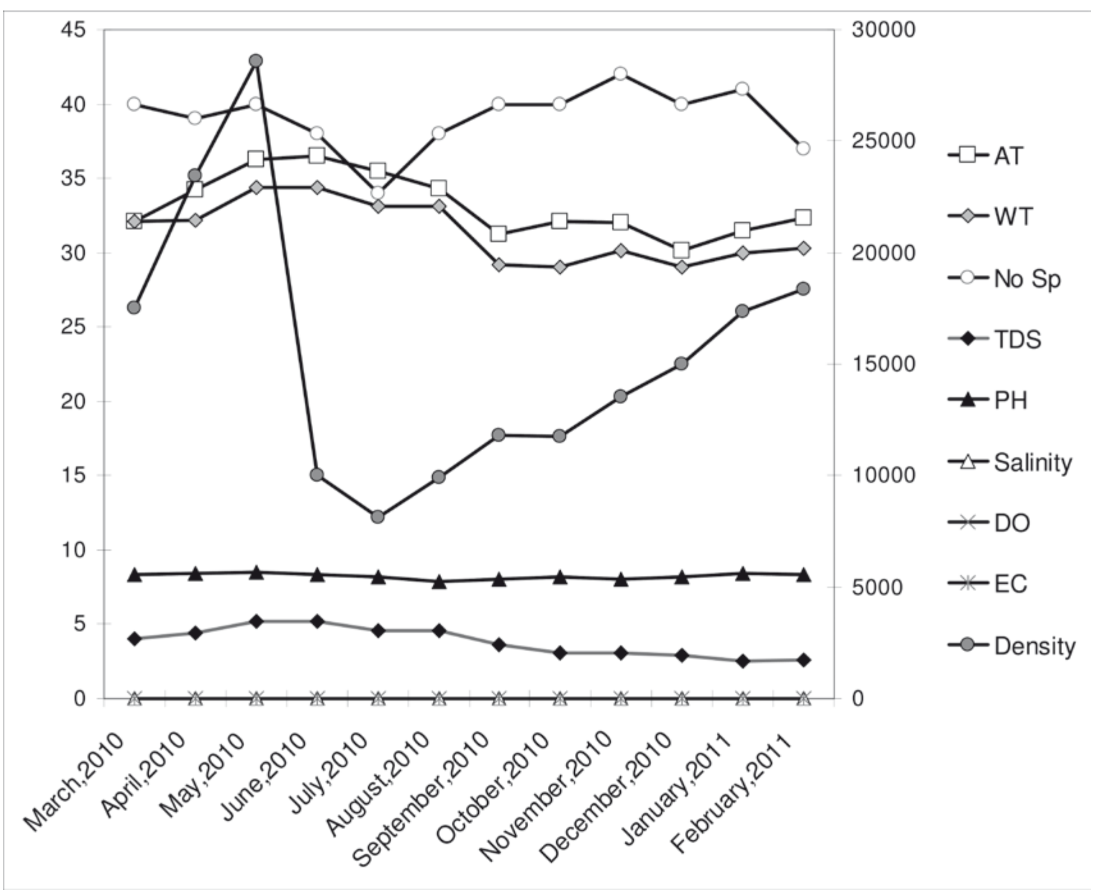

Fig. 4. Environmental variables, algal species richness and density fluctuation, March 2010-February 2011

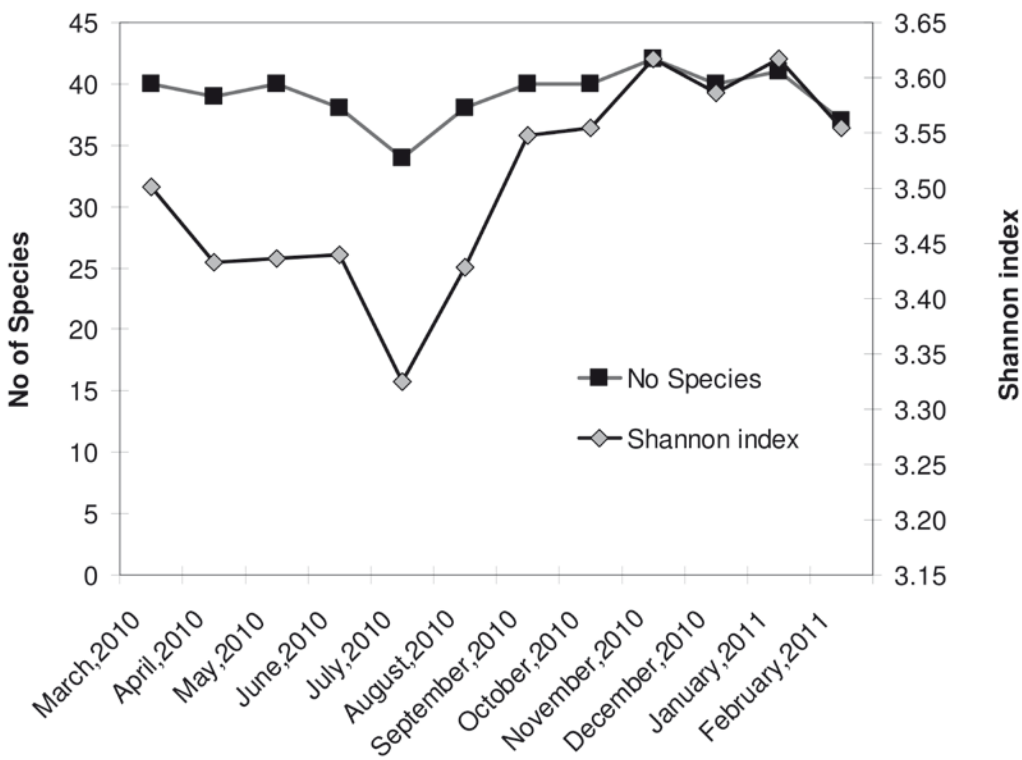

Fig. 5. Fluctuation of the Shannon index and Species Richness, March 2010-February 2011

Table 4. Details of physico-chemical parameters of the Shibpukur pool between March, 2010 and February, 2011. In the first row are given the numbers of the monitoring months between March, 2010 as 1, and February, 2011 as 12

Parameters		1	2	3	4	5	6	7	8	9	10	11	12
Air temperature (AT)	[˚C]	32.1	34.2	36.3	36.5	35.5	34.3	31.2	32.1	32.0	30.1	31.5	32.3
Water temperature (WT)	[˚C]	32.1	32.2	34.4	34.4	33.1	33.1	29.2	29.0	30.1	29.0	30.0	30.3
pH		8.3	8.5	8.5	8.3	8.2	7.9	8.0	8.2	8.0	8.2	8.4	8.3
Salinity (Sal.)	[g l^{-1}]	2.3	2.4	2.6	1.6	1.6	1.2	1.2	1.2	1.3	1.3	1.5	1.6
Dissolved oxygen (DO)	[mg l^{-1}]	3.53	3.46	4.05	2.66	3.41	3.47	4.25	4.22	4.44	4.15	4.10	4.07
Electrical conductivity (EC)	[μS cm^{-1}]	7.8	7.9	7.5	8.5	8.5	9.1	8.2	8.5	9.0	9.0	9.2	9.1
Total Dissolved Solids (TDS)	[mg l^{-1}]	4.0	4.4	5.2	5.2	4.6	4.6	3.6	3.1	3.1	2.9	2.5	2.6

Table 6. Multiple regression model enumeration

Explanatory variables	Standardized coefficients (Beta)
Air temperature (AT)	0.142 (0.610)
Water temperature (WT)	–0.694*** (–2.088)
pH	0.263 (1.972)
Salinity (Sal.)	1.231* (6.672)
Dissolved oxygen (DO)	0.554* (4.989)
Electrical conductivity (EC)	0.670** (3.558)
Total Dissolved Solids (TDS)	0.835*** (2.457)
R Square Value	0.986
F Value	39.151

Figures in parenthesis indicate t values; *, ** and *** indicate level of significance at 1, 5 and 10 percent respectively

Table 5. Correlation matrix among the physico-chemical parameters and phytoplankton density (Dens., in cells dm^{-3}) in the Shibpukur pool of the Burdwan district between March, 2010 and February, 2011. (AT – Air temperature (°C), WT – Water temperature (°C), Sal. – Salinity ($g\ l^{-1}$), DO – Dissolved oxygen ($mg\ l^{-1}$), EC – Electrical conductivity ($\mu S\ cm^{-1}$), TDS – Total Dissolved Solids ($mg\ l^{-1}$))

		AT	WT	pH	Sal.	DO	EC	Dens.	TDS
AT	Pearson Correlat.	1							
	Sig. (2-tailed)								
	N	12	1						
WT	Pearson Correlat.	0.933**							
	Sig. (2-tailed)	0.000							
	N	12	12						
pH	Pearson Correlat.	0.293	0.300	1					
	Sig. (2-tailed)	0.355	0.343						
	N	12	12	12					
Sal.	Pearson Correlat.	0.371	0.502	0.739**	1				
	Sig. (2-tailed)	0.235	0.097	0.006					
	N	12	12	12	12				
DO	Pearson Correlat.	-0.693*	-0.758**	-0.168	-0.206	1			
	Sig. (2-tailed)	0.012	0.004	0.603	0.521				
	N	12	12	12	12	12			
EC	Pearson Correlat.	-0.414	-0.446	-0.450	-0.751**	0.207	1		
	Sig. (2-tailed)	0.181	0.146	0.142	0.005	0.518			
	N	12	12	12	12	12	12		
Dens.	Pearson Correlat.	0.105	0.175	0.720**	0.863**	0.226	-0.518	1	
	Sig. (2-tailed)	0.745	0.587	0.008	0.000	0.479	0.084		
	N	12	12	12	12	12	12	12	
TDS	Pearson Correlat.	0.885**	0.909**	0.130	0.420	-0.715**	-0.612*	0.074	1
	Sig. (2-tailed)	0.000	0.000	0.686	0.174	0.009	0.034	0.819	
	N	12	12	12	12	12	12	12	12

** – Correlation is significant at the 0.01 level (2-tailed), * – Correlation is significant at the 0.05 level (2-tailed)

proposed model. Standardized β coefficients for each explanatory variable with their significance levels are described in Table 6. The R^2 value (0.986) has established the applicability of the proposed model as a fit one.

The CCA biplot (Fig. 6) was created for phytoplankton species along with environmental variables. It showed specific zones of separation depending on special preferences of phytoplankton taxa with environmental variables. Circle 1 marks the species which prefer low density assemblages. These include *Cosmarium quasillus*, *Desmidium baileyi*, and *Phormidium formosum*. Circle 2 denotes species which are indicators of acidification, including *Merismopedia elegans* and *Coelastrum sphaericum*. Species of circle 3 are impacted by high values of dissolved oxygen and can be used as indicators of oxygenation. The species placed in this circle include *Merismopedia punctata* and *Merismopedia glauca*. The triplot of CCA analysis (Fig. 7) shows phytoplankton species' abbreviated names and environmental variables. Arrows point to the month in which the marked variables are the highest. For example: DO is highest in Sept, Oct, Nov, Dec, and May (9, 10, 11, 12, and 5).

Bio-indication of species responses to the changes in environmental variables shows that the pool community preferred low alkaline, low mineralized and low organic polluted water (Table 2, Fig. 8).

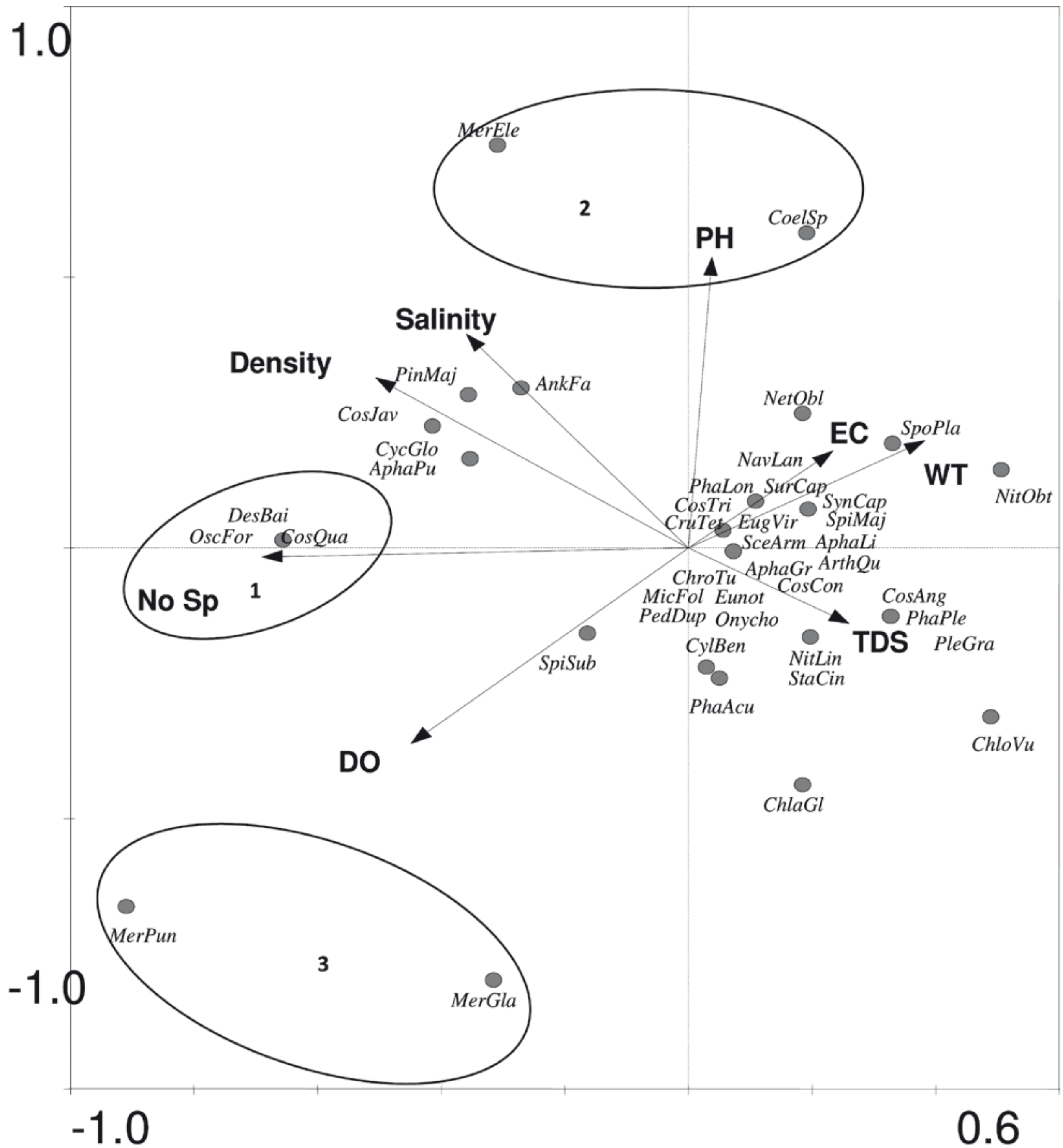

Fig. 6. CCA biplot with species abbreviated names and environmental variables. In circle 1 are marked species that are impacted by species richness. They preferred respectable low species numbers. In circle 2 are placed species that are impacted by high pH and therefore can be used as indicators of acidification. In circle 3 are placed species that are impacted by high DO and can be used as indicators of oxygenation. Species events are expressed as circles. Environmental factors are shown as arrows with the origin at their average values and extending towards higher values. pH – activity of the hydrogen ion, No sp. (number of species) – algal species richness, EC – electrical conductivity, WT – water temperature, TDS – total dissolved solids, DO – dissolved oxygen

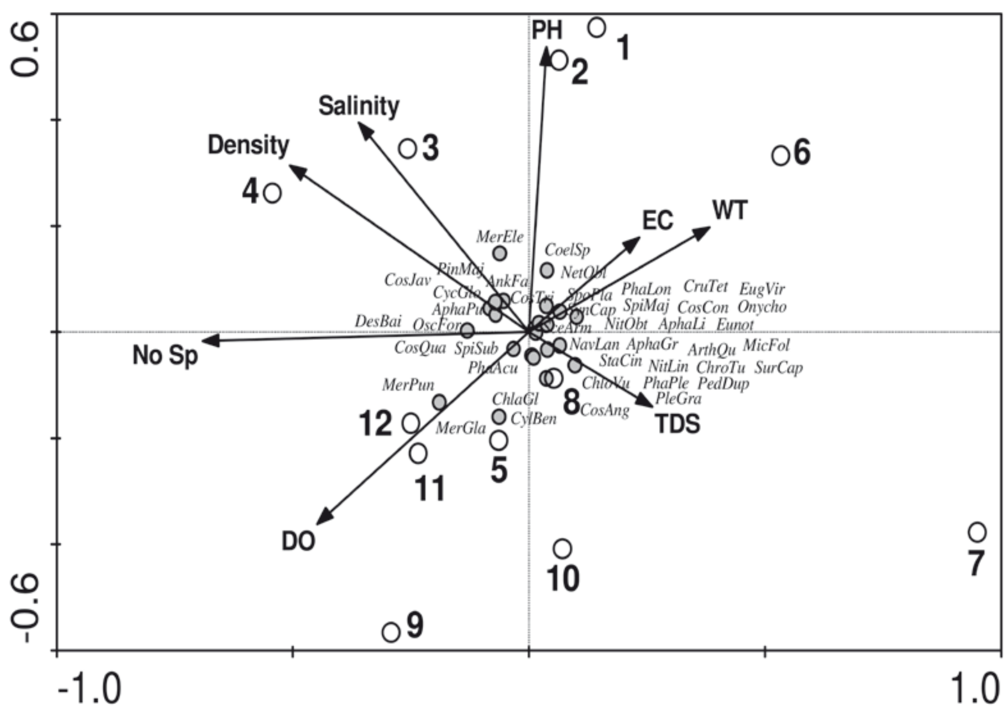

Fig. 7. CCA triplot with species' abbreviated names and month of sampling (as a number of months). Arrows point to the month in which the marked variable is highest. For example: DO is highest in Sept, Oct, Nov, Dec, and May (9, 10, 11, 12, and 5). DO is higher when water temperature is lower because directions in which arrows of DO and WT are pointing are opposing. Species richness slightly correlated with increasing of WT, Density and DO, but with lowest EC, WT and TDS. No extremely high Species richness during the studied period, communities look like a continuum

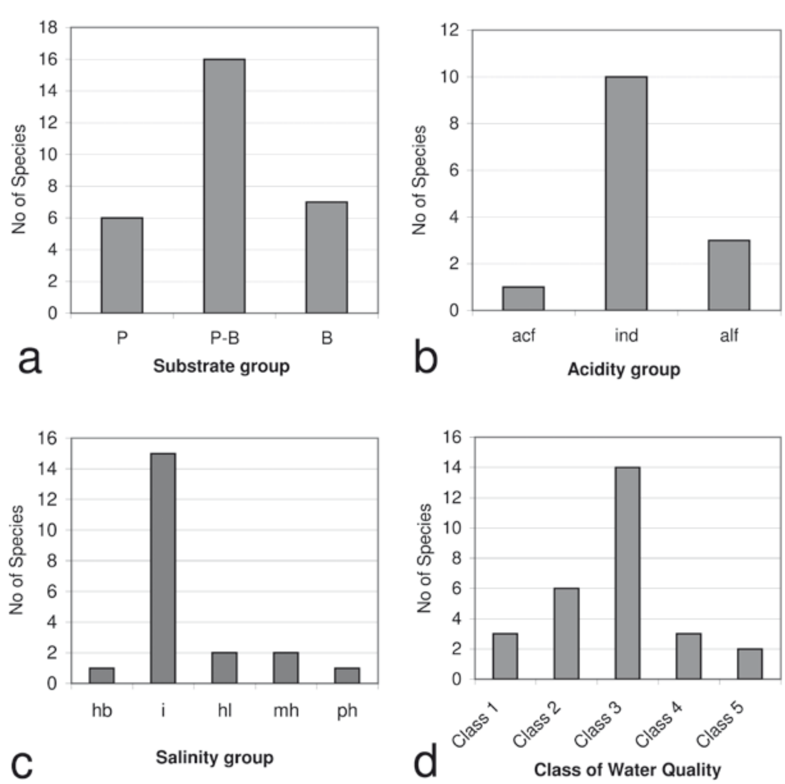

Fig. 8. Phytoplankton species composition as an indication of Substrate preferences (a), Acidity (b), Salinity (c), and Water Quality Class (d)

Discussion

This study of the tropical climate community shows two-period seasonality as was found in the Eastern Mediterranean freshwater ecosystems (Barinova et al. 2010; Barinova 2011), in which rainy season communities were more diverse and abundant (Laskar and Gupta 2009) in contrast to the diverse Central European small lakes (Dembowska 2011; Jaworska and Zdanowski 2011). In distinction, the moderate climatic zone phytoplankton communities show three periods of biomass production, which are related with the ice forming process (Dembowska 2011). Fluctuation of phytoplankton biomass and species richness in tropical lakes has a considerably smaller amplitude than in boreal lakes (Lewis 1990). Therefore, fluctuation of diversity in the Shibpukur pool with 44 species is similar to that in such pools as the Santragachi pool of North-East India in the Ganga River valley with 29 species (Ghosh et al. 2012) and Chatla Lake with 34 species (Laskar and Gupta 2009) and can be related to monsoon influence.

The Shannon-Weaver index was used to examine diversity in a categorical way which actually establishes the information entropy of the species distribution. This index considers the number of species and evenness of their distribution: an increase in evenness corresponds to a greater Shannon-Weaver value than there should be, which was supported by our results. This index also reveals the trophic status and pollution load of the water body. Our calculation of the Shannon index is similar to that for Chatla Lake (Laskar and Gupta 2009) and Santragachi Lake (Ghosh et al. 2012) in the Ganga River valley. The water body under consideration showed almost clean (Wilhm and Dorris 1968) to slight polluted status (Staub et al. 1970). Simpson's dominance index corresponds to the number of species present, along with the relative abundance of each species. Indeed, Simpson's index captures the variability of species abundance distribution. There is an opposite relationship between species dominance and diversity: when dominance increases the diversity decreases. As can be seen from our calculation, when there was maximum diversity value (3.618) in January, the dominance was the lowest (0.027).

The Canonical Correspondence Analysis (CCA) biplot (Fig. 6) shows that dissolved oxygen (DO) in the pool is higher when the water temperature (WT) is lower: the arrows of DO and WT point in opposite directions. Species richness is weakly correlated with an increase in WT, density (Dens.), and DO, but is inversely correlated with electrical conductivity (EC), and total dissolved solids (TDS). As was studied in Chatla and Santragachi Lakes in similar climatic condition, EC, WT and TDS are also major variables that impacted phytoplankton species diversity (Laskar and Gupta 2009; Ghosh et al. 2012). While in Chatla Lake 34 algal species have been found during the year-round monitoring study, we found 44 species in the Shibpukur pool phytoplankton communities during the same period. Both lakes do not show well-expressed species richness peaks during the studied period, and the phytoplankton communities are stable in respect to species content. Our CCA analysis thus reveals indicators for species richness, acidification and oxygenation. These relationships predict future changes in the ecological status of this type of water bodies.

The bio-indication method, implemented for the first time in a study of phytoplankton in Indian pools, shows three types of algal habitations: 1) planktonic, 2) planktonic-benthic and 3) benthic-periphytonic. In a small shallow pool, the attached and benthic forms mix with planktonic forms as a result of monsoon water disturbance.

The comparative floristic study, performed for the first time in Indian pools, allows clusters of phytoplankton taxa to be distinguished in respect to their taxonomic similarities and phylogenetic affinities. A similarity tree of floristic composition was constructed for the phytoplankton communities of a protected pool in the Burdwan district (Fig. 9), showing two clusters at the similarity level of 40%. The first cluster includes the phytoplankton assemblages collected in May, June, July, October, January, February and the second cluster comprises the assemblages for the rest of the year. The dendrite of floristic (Fig. 10) and Bray-Curtis analysis (Fig. 11) using the complete matrix of monthly phytoplankton communities represent similarity patterns of the two clusters of phytoplankton assemblages.

Conclusion

This paper examines the detailed information on phytoplankton composition and environmental factors and the temporal pattern of their representation in a stagnant water body that is typical of pools in North-Eastern India, which are influenced by the monsoon climate. Freshwater ecosystems are subject to various environmental impacts which cause changes in their phytoplankton composition (Cetin 2000) in particular af-

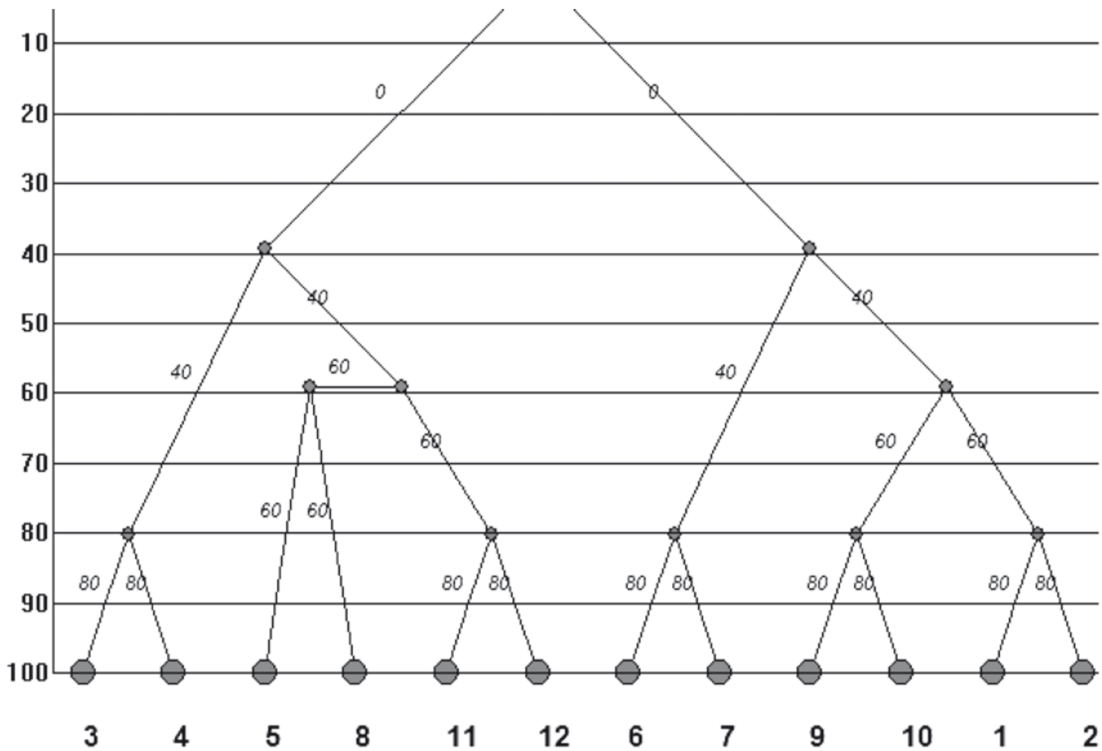

Fig. 9. Similarity tree of phytoplankton floristic composition (50% similarity level) reflects two different complexes. Here the bold number indicates the month starting from March 2011 as 1 to February 2011 as 12

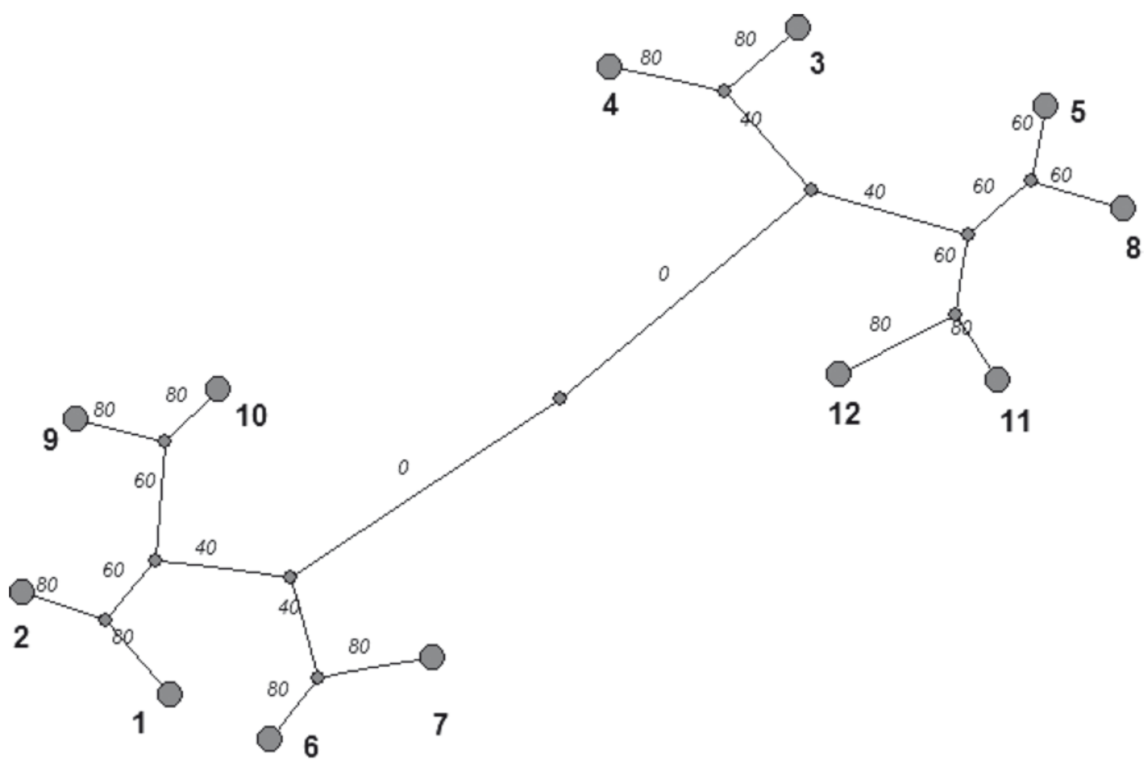

Fig. 10. Comparative species list statistics as dendrite of similarity (50% similarity level) of monthly communities. The bold number indicates the month starting from March 2011 as 1 to February 2011 as 12

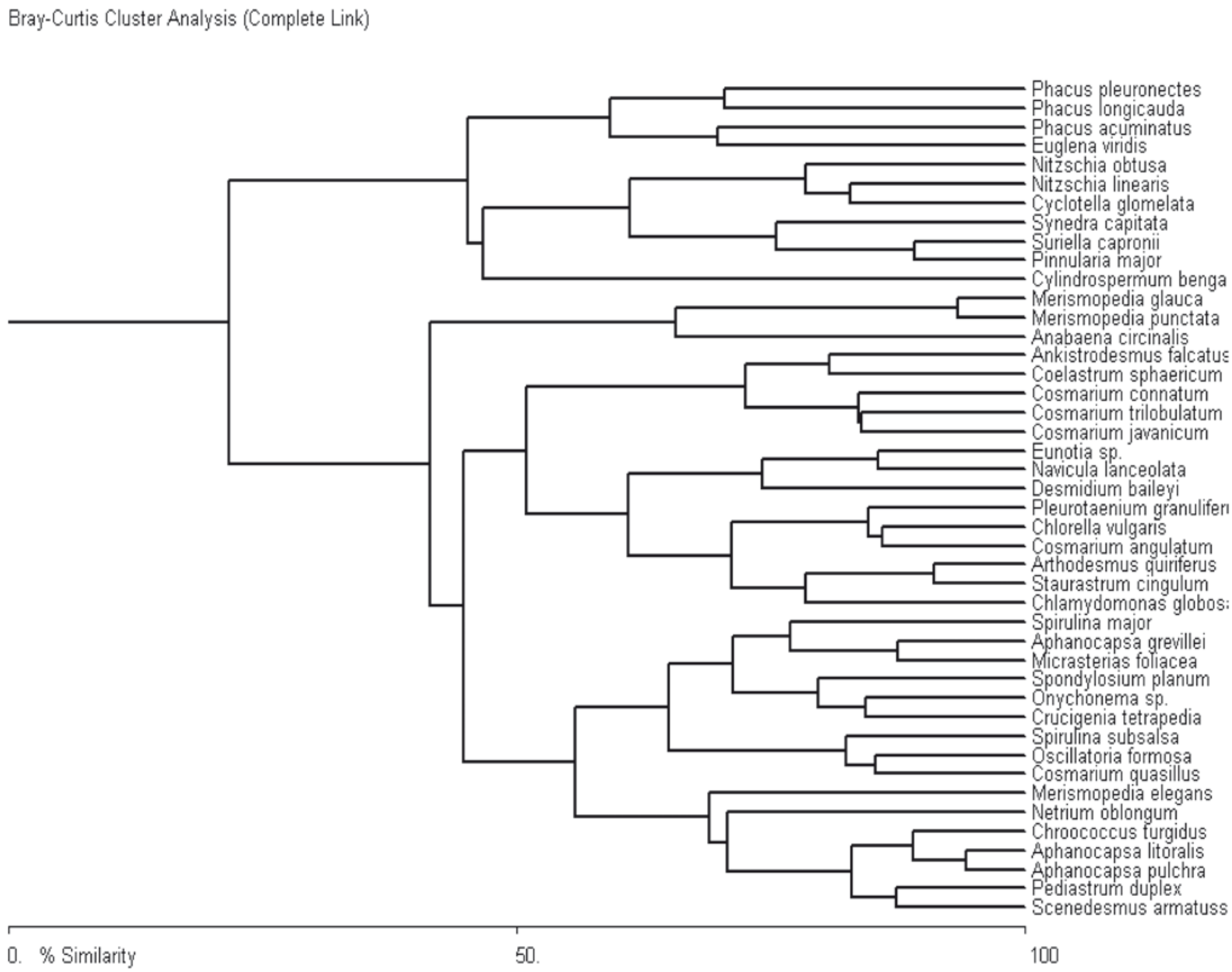

Fig. 11. Bray-Curtis cluster analysis (complete link) for establishing monthly community similarity of phytoplankton

fecting tropical lakes' phytoplankton dynamics (Melack 1979). The Ganga River valley pool communities exhibit maximal diversity of phytoplankton taxa in the monsoon season. The comparison of 44 phytoplankton species from the Shibpukur pool, an undisturbed stagnant water body in a protected area, reveals a similar pattern of species representation throughout the studied period. The successive communities form a continuum corresponding to the Constancy (C) category of (Colwell 1974). The continuum probably reflects low amplitude environmental fluctuations, stagnant water conditions and the absence of any anthropogenic or other disturbances except the monsoons. Because the Shibpukur pool phytoplankton communities are similar in variation of algal abundances and environmental variables to many other pools of the Ganga River valley (Laskar and Gupta 2009; Ghosh et al. 2012), but studied in more detail with regard to species richness, abundance, biomass, biological indices, CCA, comparison of communities, and bio-indication, it can be used as a model of aquatic community dynamics under seasonal fluctuation in the monsoon climate, applicable for monitoring of water bodies in the West Bengal Province.

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